

REMARKS

Claims 1 and 7-10 are presently pending in the application.

Claim 1 has been amended to recite that the photo initiator for cationic polymerization is the only component in the composition dissolved or dispersed in a solvent. Support for this amendment may be found in the specification at least at page 11, lines 18-22, at page 13, last paragraph, and in parts (2) and (3) of Examples 1 and 2. No new matter has been added by this amendment, and entry is respectfully requested.

In the Office Action, the Examiner has again rejected claims 1 and 9-10 under 35 U.S.C. § 103(a) as being obvious over U.S. Patent No. 5,776,634 of Ohkuma et al. ("Ohkuma") in view of WO 02/48101 of Date et al. ("Date"), relying on U.S. Patent Application Publication No. 2004/0030158 of Date as an English equivalent. Further, the Examiner has again rejected claims 7 and 8 under 35 U.S.C. § 103(a) as obvious over Ohkuma et al. in view of Date and further in view of U.S. Patent Application Publication No. 2004/0137368 of Steinmann ("Steinmann"). Applicants respectfully traverse these rejections and the arguments in support thereof for the reasons set forth previously on the record, which Applicants rely upon in full, and for the additional reasons that follow, and respectfully request reconsideration and withdrawal of the rejections.

Rejection Under § 103(a) Based on Ohkuma in view of Date

Regarding claims 1 and 9-10, the Examiner maintains that Ohkuma teaches a photosensitive recording medium composition containing a radical-polymerizable monomer, a cationic-polymerizable monomer, a radical polymerization initiator and a cationic-polymerization initiator. The cationic initiator may allegedly be represented by formula (I), which the Examiner contends is equivalent to claimed formula (I) when Ar is a phenyl group. The Examiner further argues that specific formula (II) of Ohkuma is equivalent to claimed formula (I) when M is a phosphorus atom. The Examiner acknowledges that Ohkuma does not teach the claimed purity of the cationic polymerization initiator.

However, as previously explained on the record, the Examiner argues that Date teaches a method of manufacturing sulfonium salts used as photocationic polymerization initiators for resists, including the syntheses of (4-phenylthiophenyl)diphenylsulfonium hexafluorophosphate and (4-phenylthiophenyl)diphenylsulfonium hexafluoroantimonate with a purity of 99%. Date allegedly teaches that these products contained small amounts of starting material, and thus the Examiner concluded that there is no compound represented by claimed formula (II) in the products described by Date. The Examiner takes the position that it would have been obvious for one skilled in the art at the time of the invention to use the sulfonium salts with a purity of 99% obtained in the process of Date as photocationic polymerization initiators in the composition of Ohkuma. The Examiner argues that the previously submitted data do not demonstrate a comparison of compounds commensurate in scope with the present claims and the closed prior art of record, and thus maintains that the present claims are obvious. Applicants again respectfully traverse this rejection as follows.

The presently claimed actinic radiation-curable resin composition for stereolithography includes a cationic polymerizable organic compound comprising at least one compound having an epoxy group, a radical polymerizable organic compound comprising at least one compound having a (meth)acryl group, a photo initiator for radical polymerization which is sensitive to ultraviolet light, and a photo initiator for cationic polymerization which contains a highly pure (97 weight % or higher) compound represented by formula (I) in which M is an antimony atom and which contains less than 3% by mass of a compound represented by formula (II). The compound having formula (I) is highly pure to improve the aging stability during operation and the storage stability of the composition. Applicants have determined that the stability of the resin composition may be dramatically improved by increasing the ratio of the compound having formula (I) to the compound having formula (II), that is, preferably substantially excluding compounds of formula (II). In the presently claimed composition, the photo initiator for cationic polymerization is the only component in the composition dissolved or dispersed in a solvent. None of the other components is dissolved or dispersed in a solvent and no general solvent is contained in the overall composition.

Typically, solvents are not included in ultraviolet curable resins for stereolithography because including a solvent in such a system will dramatically increase the time required for

forming a model due to waiting time for drying. In the presently claimed composition, only the photo initiator for cationic polymerization is dissolved or dispersed in a solvent because it generally occurs as a solid and cannot be homogeneously mixed into the resin composition. Accordingly, compound (I) is dissolved in a solvent, such as propylene carbonate, ethylene carbonate, etc. This solution is then utilized to form the presently claimed resin composition for stereolithography. The amount of solvent contained in the resulting composition is small because no other solvent is added.

In contrast, Ohkuma teaches at col. 11, lines 7-13:

The essential constituents of the present invention and optional additives are dissolved or dispersed in a solvent. Then the solution or the dispersion is applied on a glass plate or a transparent film as a support. After drying, a transparent film such as a polyethylene terephthalate film is laminated thereon as a retaining layer (which serves also to intercept oxygen).

In all of the Examples of Ohkuma, all of the components are dissolved in a mixture of chlorobenzene and dichloromethane (col. 12, lines 1-4). Accordingly, Ohkuma clearly does not teach that only a photo initiator for cationic polymerization is dissolved in a solvent as claimed. To the contrary, all of the “essential constituents” of the Ohkuma composition are dissolved or dispersed in a solvent to produce a solution that is applied to a substrate. The solvent is required in the Ohkuma composition because the composition is highly viscous due to the low mutual solubility of the components. Thus, it is necessary to dissolve all of the components in a solvent in order to form a solution that can be used to form a thin film. In contrast, the presently claimed composition has low viscosity (even in the absence of solvent), and the low viscosity and liquidity can be maintained over a long period.

Ohkuma thus does not teach or suggest all of the claimed elements, and Date does not cure a deficiency because Date is only cited as teaching a specific purity of a component.

It is well known in the art that solvents are not required for ultraviolet curable resins. Submitted herewith for the Examiner’s attention are two articles: “S1-3 Overview of the Markets for Radiation Curing Technology in Europe” (Proceedings of RadTech Asia ’97, presented in Yokohama, Japan November 1997) and “Low-Emission Technologies: A Path to Greener Industry” (14 RadTech Report, May/June 2005). The “Overview of the Markets” article

explains that due to increasing environmental pressures on solvent-based systems, there has been growth in radiation curing technology (using ultraviolet or electron beam).

The “Low-Emission Technologies” article describes solvent-free UV energy curing as a successful low-emission technology. Such a technology is not only environmentally friendly due to the low to zero emissions, but also provides performance advantages. UV-curing coatings are taught to be “pollution prevention” technologies because there are no emissions to control, destroy, or recycle. In contrast, solvent incineration and recovery require equipment and operating costs and generate greenhouse gases or hazardous wastes. Systems that employ UV curing thus have desirable properties, including low to zero volatile organic content (VOC) and hazardous air pollutants (HAP), lower capital investment and operating and maintenance costs than conventional ovens, and increased productivity.

In conclusion, Applicants have developed a resin composition for stereolithography that advantageously does not contain a general solvent. The Ohkuma composition is completely different because it contains a solvent for all of the components, and thus even the proposed combination of Ohkuma with Date would not teach or suggest all of the claimed elements. Applicants have also selectively determined the specific photo initiator for cationic polymerization which provides a resin with superior curing selectivity and physical strength. Such results would not have been expected based on Ohkuma, because Ohkuma does not differentiate among any of numerous possible chemical compounds depicted in cols. 9 and 10. Such unexpected results would thus overcome any *prima facie* case of obviousness which was to be established.

For at least these reasons, reconsideration and withdrawal of the § 103(a) rejection based on the proposed combination of Ohkuma with Date are respectfully requested.

Rejection Under § 103(a) Based on Ohkuma in view of Date and Steinmann

Regarding claims 7 and 8, the Examiner acknowledges that the proposed combination of Ohkuma and Date does not teach that the composition comprises an oxetane compound and a polyalkylene ether compound as claimed. However, Steinmann allegedly teaches a radiation-curable composition useful for the production of three dimensional articles by stereolithography comprising at least one cationically polymerizing organic substance, at least one free-radical

polymerizing organic substance, at least one cationic polymerization initiator, at least one free-radical polymerization initiator, at least one hydroxyl-functional compound, and at least one hydroxyl-functional oxetane compound. Accordingly, the Examiner concludes that it would have been obvious to one having ordinary skill in the art at the time of the invention to add at least one hydroxyl-functional compound, such as propylene glycols of various molecular weights, glycerine propoxylated polyether triol and polyethyleneglycols, and at least one hydroxyl-functional oxetane compound, as disclosed by Steinmann, to the composition of Ohkuma/Date in order to obtain a composition with exceptionally high photo speed, low viscosity, low humidity sensitivity, and high temperature resistance since such properties are taught by Steinmann. Applicants again respectfully traverse this rejection as follows.

As explained above, even the proposed combination of Ohkuma and Date would not teach or suggest all of the claimed elements, including a resin composition for stereolithography in which only the photo initiator for cationic polymerization is dissolved or dispersed in a solvent. Steinmann would not cure such a deficiency because the proposed combination with Steinmann would only result in inclusion of a hydroxyl-functional compound in the Ohkuma/Date composition, which would still require the solvent taught by Ohkuma.

Further, as previously demonstrated on the record, it would not have been expected based on the proposed combination of Ohkuma with Date that preparation of a resin composition containing as a photo initiator for cationic polymerization the claimed compound having formula (I) in which M is antimony yields dramatic and superior properties relative to those which are obtained when M is phosphorus. Further, such results would also not have been expected based on the proposed combination of Ohkuma, Date, and Steinmann, since Steinmann does not teach or suggest the claimed compound having formula (I). Accordingly, reconsideration and withdrawal of the §103(a) rejection based on Ohkuma in view of Date and Steinmann are respectfully requested

In view of the preceding Amendment and Remarks, it is respectfully submitted that the pending claims are patentably distinct from the prior art of record and in condition for allowance. A Notice of Allowance is respectfully requested.

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Respectfully submitted,
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(Date)

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“S1-3 Overview of the Markets for Radiation Curing Technology in Europe”
(Proceedings of RadTech Asia '97, presented in Yokohama, Japan November
1997)

“Low-Emission Technologies: A Path to Greener Industry” (14 RadTech Report,
May/June 2005)

RadTech Asia'97

Proceedings

RadTech Asia'97



**Pacific Convention Plaza Yokohama
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OVERVIEW OF THE MARKETS FOR RADIATION CURING TECHNOLOGY IN EUROPE

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I. INTRODUCTION

Radiation curing technology (Ultraviolet, UV, and electron beam, EB) is applicable to a wide range of coating, ink, and adhesive applications. Very active research and development has produced continuous product advances leading to penetration into many new markets. In addition, environmental (VOC) pressures on solvent-based systems provide growth opportunities for this compliant technology. Although still a small segment of the overall coatings market (ca. 3%), radiation curing is increasingly the technology of choice to solve VOC and/or performance problems. In fact, radiation curing is maturing in many market segments to where it is now the norm rather than the exception. The European markets are also being shaped by globalization of the technology. More and more we see consolidation at the ink and coating formulator level resulting in large multi national groups. This tends to globalize the technology, which should result in market growth.

Finally, with the recent strengthening of the U.S. dollar, European suppliers should be more competitive in the global markets. This is also a positive factor for sustained growth of the technology in Europe in 1997.

II. MARKET BY TECHNOLOGY

Acrylate, free radical polymerization is the dominant radiation curing technology used today. It is estimated that the market for these products is approximately 32,000 tons/ year and growing at a rate of 5-7% /year.

A significant amount of unsaturated polyester/styrene is still utilized in wood coatings approximately 10,000-12,000 ton/year. This volume is believed to be decreasing due to the VOC pressures on styrene.

Cationic polymerization technology utilizing cycloaliphatic epoxies, glycidyl ether epoxies, and vinyl ethers are estimated at 500-600 tons/year. Growth is comparable to acrylates, 5-7% /year.

TABLE I
EUROPEAN MARKET SIZE* BY TECHNOLOGY

CHEMISTRY TYPE	TONS/YEAR	%
ACRYLATES	32,000	73
UNSAT. PH	10,000-12,000	25
CATIONIC	500-600	2

* Does not include photoinitiators, additives, etc.

III. MARKET BY APPLICATION

The markets for acrylate products are estimated in the following table:

TABLE II
ESTIMATION OF 1996 EUROPEAN MARKET BY APPLICATION

APPLICATION FIELD CENTER	TOTAL MARKET IN TONS
EBC	1500
SILK SCREEN (UV)	2300
WOOD+PLASTIC+CORK (UV)	11,000
OPV (UV)	7700
OFFSET (UV + EBC)	8000
OTHERS	1500
TOTAL	32,000

Comprised of OPV, offset inks, and screen inks, graphic arts is the largest end use segment for acrylate technology 18,000 tons or 56% of the total. This does not include flexo inks (particularly for narrow web presses) which is still a small (200-300 tons/year) but very fast growing segment (15-20%/ year). The OPV segment is one of the end uses which is maturing. A relatively few high volume, core products are used. Radiation curing technology has a major share of the OPV market (ca. 50%). Offset printing is uniquely suited for UV and new innovations will lead to further penetration of the technology. Screen inks are showing good growth particularly for CD decoration.

Coatings for wood and laminates, plastics and cork represent the next largest share, 34%. In the wood area high performance coatings for furniture foil (laminated to particleboard) are showing good growth. UV coatings for flooring (PVC and wood) remains a solid end-use for the technology. Protective UV coatings for heat sensitive plastics continue to be of interest.

Electron beam coatings (EBC) represent several large specialty applications and comprises 5% of the market. Growth in these areas is mostly stepwise as a new application is commercialized. Applications are coatings for outdoor panels, paper and foil upgrading, doors, and furniture.

The category other applications includes UV glass / glass lamination, fiber optics coatings and electronics.

Coatings for metal remain largely in the domain of the other (non-Rad cure) technologies, however some inroads are being made by cationic. A large part of the market for cationic technology is in metal coatings. It is believed that a major producer of 2 piece aluminum beverage cans will be converting to UV coatings in the future. If so this will be a significant growth opportunity. Cationic is also seeing considerable development in the flexo market previously mentioned.

IV. MARKETS BY COUNTRY

Estimation of the market sizes for acrylates by country is shown below:

TABLE III
ESTIMATION OF THE EUROPEAN MARKET
BY COUNTRY, 1996

COUNTRY	TOTAL MARKET IN TONS
A	400
B	1400
CH	2500
D	5500
E	1100
F	5500
GB	7000
I	4200
NL	1400
P	500
SCAND.	2500
TOTAL	32,000

The single largest market for radiation curing products is in Great Britain, 7000 tons. The largest application segment is in graphic arts (85%). Market growth is estimated at 8% / year. The French and German markets are comparable in size, 5500 tons. However, the French market showed a decline in 1996 vs. 1995 whereas Germany showed excellent growth, ca. 10%.

UV/EB in Germany is dominated by wood applications (~ 60% of the total) including several EB lines for furniture foil. Graphics arts comprise the balance. France's markets are more or less equally split between wood and graphic arts. The Italian market, 4200 tons, is split approximately 60% graphic arts and 40% wood. Growth was 5%. The wood market in Italy is very large (> 150,000T) but penetration of acrylates has been small presumably in part due to the price sensitivity of many of these segments (competition vs. unsat polyester). Perhaps if regulatory compliance for VOC became more stringent, acrylates will show more growth.

UV applications in Scandinavia are dominated by wood and in 1996 this industry suffered a recession. Consequently, no growth was seen. Scandinavia depends on the rest of Europe as its market and with a weak economy and stiff competition from eastern block countries, it has to struggle to maintain its position. 1997 has seen some turnaround.

Belgium plus Holland represents a 2800T market which showed excellent growth in 1996, 16%. Major applications are offset and EBC. Both applications have shown good growth.

Switzerland is mostly graphic arts (~90%) largely OPV. Growth has been exceptional (>20%) helped a lot by the increased competitiveness of European exports.

Spain and Portugal host a unique cork market and UV coatings are used extensively. Acrylate UV still competes with unsat polyesters for this and the wood market in general. Growth has been decent, 6%.

Eastern Europe remains an unknown at this point. As the economics open up and grow it can be expected that radiation curing will find its place. However, no significant opportunities are foreseen in the next few years.

V. OUTLOOK

There are many factors which bode well for the continuing growth of radiation curing technology in Europe. The economics of Europe has recovered appreciably from 1995-1996. Europe is more competitive in the rest of the world due to the strong U.S. dollar (weaker European currencies). Pressures on VOC are becoming stricter. Product technologies continue to evolve including hybrids such as UV powders and waterborne UV. The number of new, emerging applications are many including:

- Optical lenses
- Coatings for electrical sleeves
- Binders for abrasive papers
- Binders for composites
- Textile printing

If there is any weak point, it is the maturation of certain large market segments like OPV where growth can be expected to be lower with strong pricing pressure. 1997 is expected to show good growth in Europe at the high end of the 5-7% growth range. Significant breakthrough in new developments could increase this further.

*www.radtech.org/documents/
lowemissiontechnologies.pdf*

Low-Emission Technologies: A Path to Greener Industry

By Ronald Golden

Solvent-free ultraviolet (UV) energy curing is a low-emission technology that has a proven record of success in many industrial ink, coating and adhesive applications. While the environmental benefits of this technology are well known, it is not so well recognized that the economics also can be very favorable. This paper will report on several case studies of successful industrial applications of these "green" technologies to quantify the achieved environmental and economic benefits.

Low to zero emission ultraviolet (UV) energy curing has been in commercial use for several decades. In addition to performance advantages, the environmental benefits of these technologies have driven their adoption and rate of growth substantially faster than conventional and even water-borne inks, coatings and adhesives.

Techno-economic models can be used to determine whether these technologies are an appropriate option for higher productivity and pollution prevention.

Finally, workplace safety aspects will be considered.

Introduction

Low to zero emission ultraviolet (UV) energy curing has been in commercial use for several decades. In addition to performance advantages, the environmental benefits of these technologies have driven their adoption and rate of growth substantially faster

than conventional and even water-borne inks, coatings and adhesives. It should be noted that UV-curing coatings are true "pollution prevention" technologies. There are no emissions to control, destroy or recycle. In contrast, solvent incineration and recovery require additional equipment investment and operating costs, and these technologies generate either incremental greenhouse gases (see Coors Light Case Study, p. 16) on hazardous wastes.

However, while the environmental benefits of UV-curing coatings are well known, many discussions of these technologies have emphasized the investment required to convert existing lines, the higher cost of materials and perceived safety issues. These arguments in some cases have overshadowed the positive economics and improved performance, productivity and safety of these technologies. In the absence of a total economic analysis, it was difficult to quantify these environmental and economic benefits. During the past five years, case studies have been published that provide details concerning the reduced emissions and economics of UV-curing coating installations. Summaries of several of these studies, ranging from a large, world-scale can coating line to a small wood coating shop, are presented here with the objective of providing an overall perspective of the costs, benefits and economic returns to install and operate these green coating technologies.

This broader perspective, combined with existing and emerging economic modeling tools, provide a basis for a

rational decision on whether "low to zero emission" technologies are appropriate for a specific application.

UV Curing

UV curing was introduced commercially about 30 years ago, and the advantages are well known:

- Low to zero volatile organic content (VOC) and hazardous air pollutants (HAP).
- Lower capital investment, operating and maintenance costs than conventional ovens (smaller footprint, easy to install or retrofit in existing space, no need to heat and move large volumes of air).
- Lower operating costs and maintenance.

- Increased productivity ("instant" curing, fast-line speed, reduced dust and dirt contamination of wet coating, immediate processing and handling of finished product).
- Special appearance and performance features (wide formulating latitude, high gloss, toughness, high cross-link density, (improved chemical/abrasion resistance).
- Lower energy costs.
- Unexposed liquid coating does not dry or cure in air (viscosity stability, clean-up is easier and requires less solvent, excess coating can be recycled for high-transfer efficiency).
- Reduced fire and explosion hazard.

Disadvantages and limitations of UV curing include:

- Typically higher costs for UV-coating materials.
- High viscosity can impose processing limitations.
- Coating thickness and pigments can limit cure speed or even prevent complete curing.
- Shadow areas and crevices may prevent curing of unexposed coating.
- Acrylate shrinkage may cause adhesion problems on rigid substrates.
- Acrylates can cause skin irritation if not handled properly.

This last point, the potential for skin irritation, deserves some comment. When UV curing first was introduced

TABLE 1

Comparison of solvent and UV-curing materials

Chemical	Flash Point	VOC	Hazardous Waste	Skin/Eye Irritant*	Systemic Toxicity*	Mutagen*
VM&P naptha	<0°F	Yes	Yes	No	Yes	No
Toluene	40°F	Yes	Yes	Yes	Yes	Yes
Xylenes	100°F	Yes	Yes	Yes	Yes	Yes
4-Methyl-2-pentanone	63°F	Yes	Yes	Yes	Yes	No
1-Butanol	100°F	Yes	Yes	Yes	Yes	Yes
2-Butoxy ethanol	160°F	Yes	Yes	Yes	Yes	Yes
1-Methoxy-2-propanol	100°F	Yes	Yes	Yes	Yes	No
2-Butoxyethyl acetate	190°F	Yes	Yes	Yes	Yes	No
2-Ethoxyethyl acetate	117°F	Yes	Yes	Yes	Yes	No
1,1,1-Trichloroethane	None	Yes	Yes	Yes	Yes	Yes
HDODA**	270°F	No	No	Yes	No	No
TMPTA**	>212°F	No	No	Yes	No	Yes
TRPGDA**	>212°F	No	No	Yes	Some evidence	No
PETA**	>200°F	No	No	Yes	No	Yes
3,4-Epoxy cyclohexyl methyl 3,4-epoxycyclohexane carboxylate	245°F	No	No	Yes	No	Yes
Acrylate Oligomers	>>212°F	No	No	Yes	No	No

* Canadian Centre (1997); Lewis, Sr. (1992); Union Carbide (1993)
 ** HDODA = hexanediol diacrylate; TMPTA = trimethylolpropane triacrylate; TRPGDA = tripropylene glycol diacrylate; PETA = pentaerythritol triacrylate

as a commercial technology, a few of the newly developed acrylates were quite irritating, and some of the basic acrylic monomers used were relatively toxic. Workers who were accustomed to frequent direct skin contact with solvents and solvent formulations continued to treat the new UV-curing materials in the same way. While the toxic effects of solvent exposure may not be immediately apparent, the skin rash, which can quickly result from improper handling of acrylates, led to a poor reputation for workplace safety. Most of the more irritating acrylates no longer are used in UV curing, and newer, less irritating materials have been developed. The fact that solvents can be abused without immediate apparent effect is not a benefit; just the opposite. In fact, a rational comparison with solvents (Table 1) shows that, in general, currently available UV-curing materials are actually less hazardous.

Good industrial hygiene practices, knowledge of safe handling procedures and worker training are essential for safe handling of any chemical. When these principles are followed, experience has shown that UV/EB-curing technology can be handled safely in industrial applications.

A guide to safe handling of UV-curing materials is available on the RadTech International North America Web site www.radtech.org.

UV-Curing Case Studies

The following case studies provide data on the costs and achieved economic benefits of UV-curing installations over a range of industrial applications. Note that the data will typically show mid-1990s costs for capital, materials and energy.

Coors Brewing Company, Golden, Colorado (Brady et al., 1997)

This is a true total media study. It includes not only an analysis of the

TABLE 2

Total industrial installation and utility source emissions (metric tons/billion cans)

Emissions	Process		
	Water-borne Thermal, Uncontrolled	Water-borne Thermal + Incineration	UV Curing
Nitrogen Oxides	8.1	11.6	6.5
Sulfur Oxides	18	23	18
Particulates	25	29	24
VOC	28	0.56	0.52
HAP	11.5	0.23	0.12
Non-Methane HC	0.048	0.096	0.02
CO	0.52	1.11	0.15
CO ₂	2,909	5,182	1,727
Ozone	Not Measured	Not Measured	0.0019*

*) At the UV oven exhaust

TABLE 3

Total industrial installation and utility energy usage (million BTU/billion cans)

Emissions	Process		
	Water-borne Thermal, Uncontrolled	Water-borne Thermal + Incineration	UV Curing
Electricity	16,300	19,500	15,900
Natural Gas	23,900	60,100	0
Total	40,200	79,600	15,900

emissions and costs of the industrial installation, but also provides data for the emissions from the electric utility and the pollution control solvent incineration unit. It should be noted that the original technology that was replaced was water-borne coatings, and that even these contain substantial quantities of VOC that had to be incinerated to achieve the same emission level as the uncontrolled UV-curing process.

Application: Exterior Aluminum Can Decoration and Coating, One Billion Cans/Year Production Line.

Original Process: Thermal curing, water-based ink, varnish and bottom coating.

New Process: UV curing ink, varnish and bottom coating.

Benefits Achieved: Table 2 shows that although incineration controls with water-borne inks and coatings can achieve the same level of VOC and HAP

TABLE 4**Economic summary (\$/billion cans)**

	Process		
	Water-borne Thermal, Uncontrolled	Water-borne Thermal + Incineration	UV Curing
Capital*	803,000	1,280,000	428,000
Electricity	171,800	207,000	170,000
Natural Gas	170,600	428,000	0
Raw Materials	1,010,000	1,010,000	1,180,000
Operation/ Maintenance	41,800	192,000	21,200
Total Costs	2,197,200	3,117,000	1,799,200
*) 10 year amortization			

emissions as UV curing, this must be at the expense of increased emissions of hydrocarbons (HC) and carbon, nitrogen and sulfur oxides. Note that ozone emissions are negligible, even directly at the UV oven exhaust.

Similarly, Table 3 shows the substantial additional energy cost for the controlled water-borne system to achieve the same low level of emissions as the UV installation.

Table 4 shows a comparison of the total economics of the three process options.

The following case studies are not so detailed, but equally demonstrate the environmental and economic benefits of UV curing in large and small installations.

Hussey Seating Company, North Berwick, Maine (Northeast States, 1997)

Application: Wood Finishing, Stadium Seating.

Original Process: Brush-applied two-coat solvent polyurethane varnish, slow air drying. 1993 emissions were 45 metric tons/year of VOC (9 metric tons/year HAP).

New Process: Automated UV-cured roll coat sealer, followed by UV-cured

vacuum coated topcoat, instant dry and stacking, coating cost 8% higher than conventional material, coating transfer efficiency increased to nearly 100%, 23% less coating used/unit.

Capital And Training Costs: \$320,000.

Benefits Achieved (Table 5):

- Production increased 55% from 9,000 to 14,000 units/week without adding extra space.
- VOC and HAP emissions reduced 98% and 90%, respectively to 100 kg/year.
- Substantially reduced clean-up and waste.
- 17% lower coating cost/unit.

- Improved coating durability.
- 67% reduction in labor requirements.

Kidde-Fenwal, Inc., Ashland, Massachusetts (Commonwealth of Massachusetts, 1996)

Application: Printed Circuit Boards.

Original Process: High-pressure spray, 479 liters of low solids epoxy solvent conformal coating/10,000 boards, 24-hour post cure, 1995 emissions were 13 metric tons/year of VOC (60% toluene), air permit required, regulatory limitations on formulation VOC.

New Process: Low-pressure spray, 15 liters of UV-curing polyurethane/10,000 boards, instant cure.

Benefits achieved: estimated greater than \$300,000/year:

- VOC emissions reduced by 75%.
- Eliminated 1,530 liters/year of clean-up solvent.
- Eliminated 20 drums/year of flammable waste.
- Eliminated storage of 1,800 kg of flammables on site.
- Regulatory permit fees reduced from minimum \$2,000/year to about \$150/year.
- Coating material/unit reduced 98%.
- Process cycle time reduced by 24 hours, work in progress reduced by \$50,000/year.
- Elimination of masking \$75,000/year.
- Labor savings 14,000 worker hours/year.

TABLE 5**Economic summary**

Factor	Savings/(Cost)
Capital And Training	\$320,000
Labor	\$280,000/year
Materials	\$55,000/year
Expansion cost avoidance	\$200,000
Payback period	4.5 months

E&I Industries, Woodridge, New York (EPRI 1999)

Application: Wood Moldings, Brush Blocks, Tool Handles

Original Process: Solvent lacquers applied by spray and gasket dipping, thermal dry, processing time 10 to 20 minutes.

New Process: Vacuum coating, UV cure, line speed 18 m/min.

Capital Costs: \$35,000 (used vacuum coater and UV equipment).

Benefits achieved:

- VOC emissions reduced by 99%, greatly reduced workplace exposure to solvents.
- Improved chemical, chip and abrasion resistance.
- More consistent film weight and coating appearance.
- Short coating open time—reduced airborne contamination.
- Reduced surface defects.
- Reduced rejects.
- Process cycle time reduced to less than one minute.
- Coating material costs reduced 61% from \$0.04125/piece to \$0.016/piece.

Techno-Economic Models

While UV curing can offer environmental and economic benefits, many factors must enter into selection of the optimal pollution prevention or control technology for a specific application. The basis for a decision can range from sophisticated performance and engineering studies to personal preference. Fortunately, some techno-economic modeling tools readily are available or are being developed to help make these critical decisions.

A *UV Powder Resource* CD-ROM (2000) is available through RadTech. It includes a spreadsheet "UV Powder vs. Liquid Paint Cost Comparison." It is similar to the conventional powder coating model published by The Powder Coating Institute, but in

addition takes into account the special features of UV-curing powder coatings.

RadTech is also working to develop an economic analysis model comparing UV-curing and conventional liquid coatings.

Conclusion

Rapid economic growth and industrialization will continue for the foreseeable future, as a growing world population strives to maintain and improve quality of life. Unless there is a global commitment to reduce and eliminate emissions and wastes, such economic growth will be at the expense of the environment. Unfortunately, it has been a common perception that investment in environmental protection must always result in a net increase in costs or sacrifice in coating performance. Recently published case studies demonstrate that installation of low-emission manufacturing processes can yield substantial environmental benefits and substantial positive economic returns.

There is no one best technology to achieve the lowest possible emissions and wastes in combination with the highest economic return. Each application must be considered on its own. Techno-economic models are just now becoming available that enable end-users to make rational decisions concerning optimal means to achieve environmental and economic objectives. Recognizing and promoting the positive economic benefits of "green" technologies will be essential to achieving greater acceptance and enthusiasm for their adoption. ■

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